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## Probabilistic Prediction for Improved Scientific Understanding and Improved Decision Making

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**Introduction:** In recognition of the importance of quantifying uncertainty in atmosphere-ocean forecasting for the purpose of managing operational risk, NRL-Monterey (MRY) is involved in several related efforts in support of the design, utility, and evaluation of forecasts that utilize and quantify uncertainty. NRL-MRY recently stood up the Probabilistic Prediction Research Office (PRO) to help facilitate and coordinate these efforts. The PRO also reaches out to users, decision makers, and funding agencies to better understand the environment in which meteorology and oceanography (METOC)-related decisions are made and to identify situations in which probabilistic environmental information can be utilized.

NRL-MRY research efforts that attempt to exploit uncertainty information for improved understanding and decision making include the following: research on the design of the global atmospheric ensemble forecast system; research in the use of stochastic parameterizations to account for model uncertainty, which holds promise for improved ensemble forecasting of tropical cyclone track forecasts; the design of a new mesoscale atmospheric ensemble forecasting system, which accounts for model uncertainty through varying parameters in the physical parameterization schemes and perturbing sea surface and land surface forcing; use of ensemble-based covariances for data assimilation and adaptive observing applications; use of ensemble forecasts at the urban scale to quantify risk in the event of a toxic release; and the use of ensembles to learn about and improve model parameterizations. Some of these efforts are described below.

**Global Modeling:** Ensemble forecasting attempts to quantify forecast uncertainty by running many realizations of a numerical weather prediction (NWP) model, each from a different initial condition and/or each being a different version of the forecast model. The research efforts on global atmospheric weather forecast model ensemble design have focused on both the initial uncertainty problem and the model uncertainty problem. The ensemble transform (ET) method combines flow-dependent information from short-term forecasts with error statistics from the data assimilation system to produce initial perturbations that are balanced and conditioned for growth. The ET scheme has been found superior to the current operational scheme under a variety of metrics, including lower ensemble mean rms errors and a stronger relationship between ensemble variance and forecast error variance.

In addition, a stochastic scheme has been developed to account for uncertainty in the physical parameterization of moist convection. Implementation of this scheme has led to improved ensemble performance in the tropics under a variety of measures. The stochastic convection ensemble also appears to provide useful information for 4- to 5-day tropical cyclone track forecasts, providing ensemble mean forecasts of comparable skill to the multi-model consensus forecast, averaged over the 2005 season (Fig. 6 shows one case).

**High-Resolution Regional Modeling:** One of the attractive features of the ET ensemble generation technique is that it enables uncertainty information to be sampled at the scale of the simulation model. This is critically important for applications such as characterizing the uncertainty in forecasts of toxic plume dispersion in urban areas. Figure 7 depicts an ensemble of plume forecasts from two distinct release sites near Tokyo, Japan. If civil protection agencies had access to only a single forecast (mbr000), there would be a danger that they would not be cognizant of the many other areas that might be affected (indicated by the plumes mbr001 through mbr010). Apart from accounting for uncertainties in initial conditions, the ensemble simulations also accounted for uncertainties in the representations of urban and sea surface temperature effects on the plumes.

Physical parameterizations for processes such as surface heat and moisture exchange, boundary layer mixing, clouds, and precipitation also have inherent uncertainties in their formulations. For example, parameterization coefficients, which are often derived for a specific circumstance and then applied to all meteorological conditions, should be represented by a wider spectrum of values or, more accurately, by a probability density function if it is known. Preliminary research is under way to gain a better understanding of how to represent these uncertainties within the COAMPS®* suite of physical parameterizations appropriate for the mesoscale. Our current method involves working with parameterization experts along with executing a series of model experiments to identify the most critical parameters and estimates of their uncertainties. A different parameter value is then chosen for each ensemble member. Ensemble verification statistics are used to diagnose which parameters are most sensitive. In the example shown in Fig. 8, model-predicted clouds are shown to be sensitive to various parameters in boundary layer representation. None of the four boundary layer representations agree particularly well with the satellite image; however, the clouds derived

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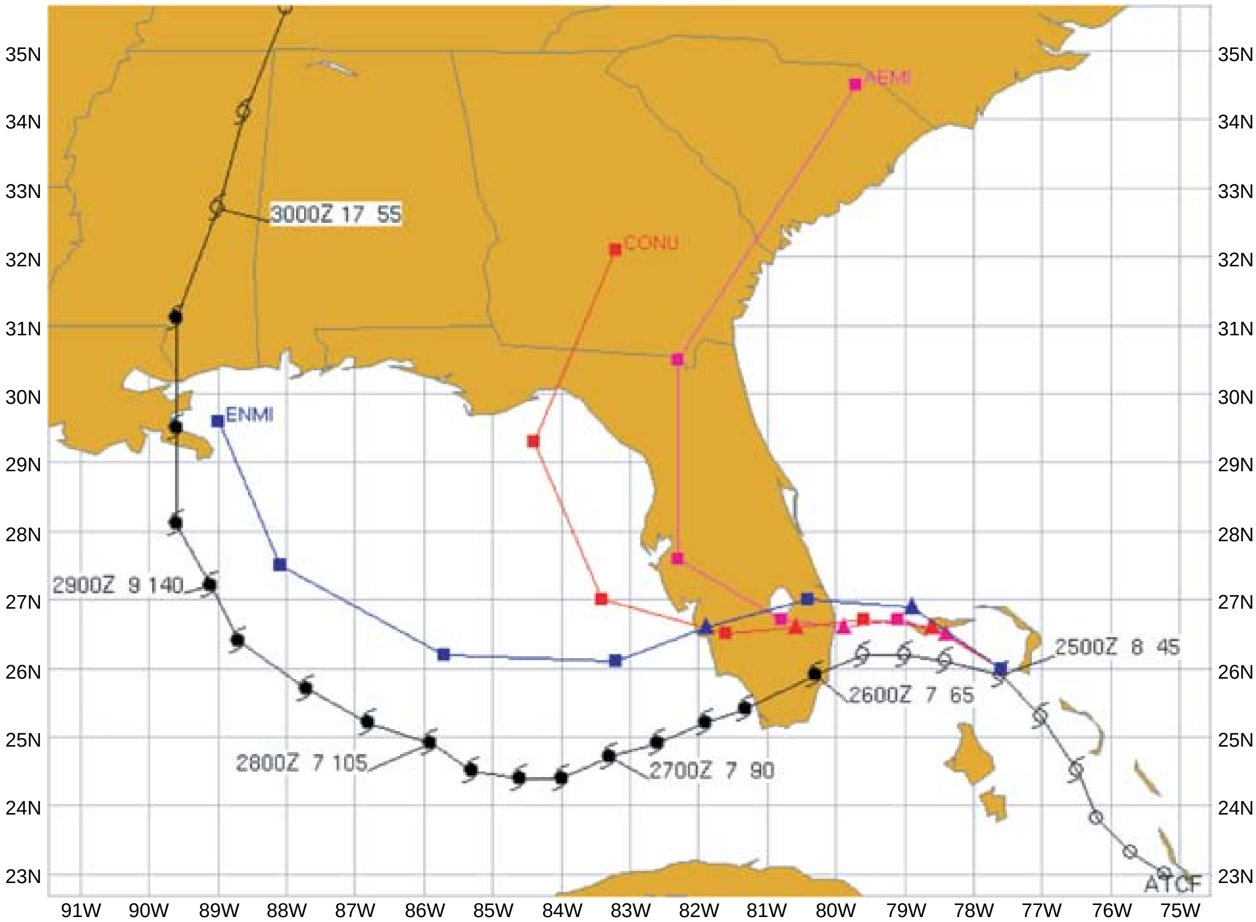


**FIGURE 6**
Tropical cyclone track forecasts for Hurricane Katrina, from 25 Aug. 2005, 00 UTC. The black track gives the observed storm track, the red track gives the multi-model consensus forecast, the pink track gives the NOAA Global Forecast System ensemble mean forecast, and the blue track gives the new ET-stochastic convection ensemble mean forecast.

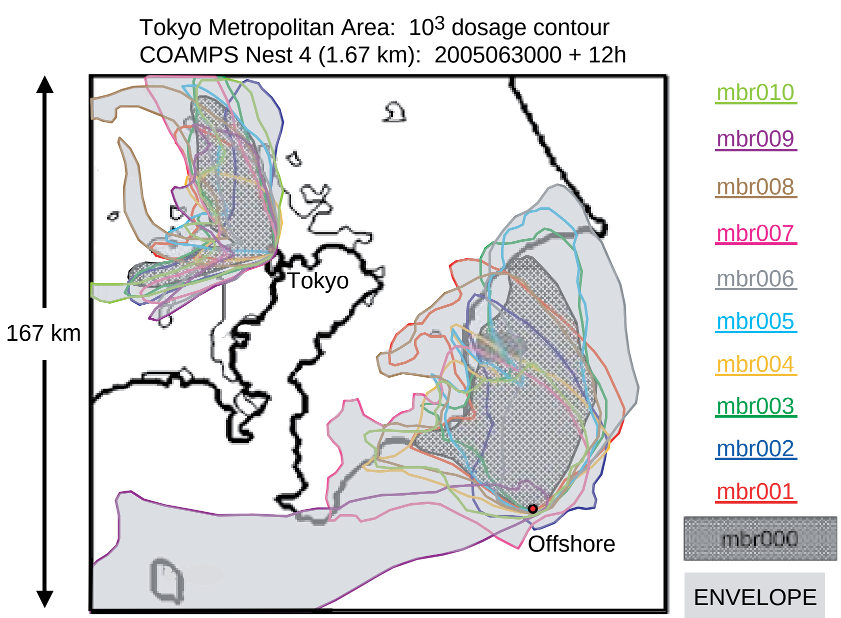


**FIGURE 7**
An ensemble of plume forecasts from two distinct release sites near Tokyo, Japan. Different colors represent different ensemble members. The dark shaded plume, mbr000, is what would be available if only a deterministic forecast system were employed.

from the ensemble mean are in the best agreement with the observations.

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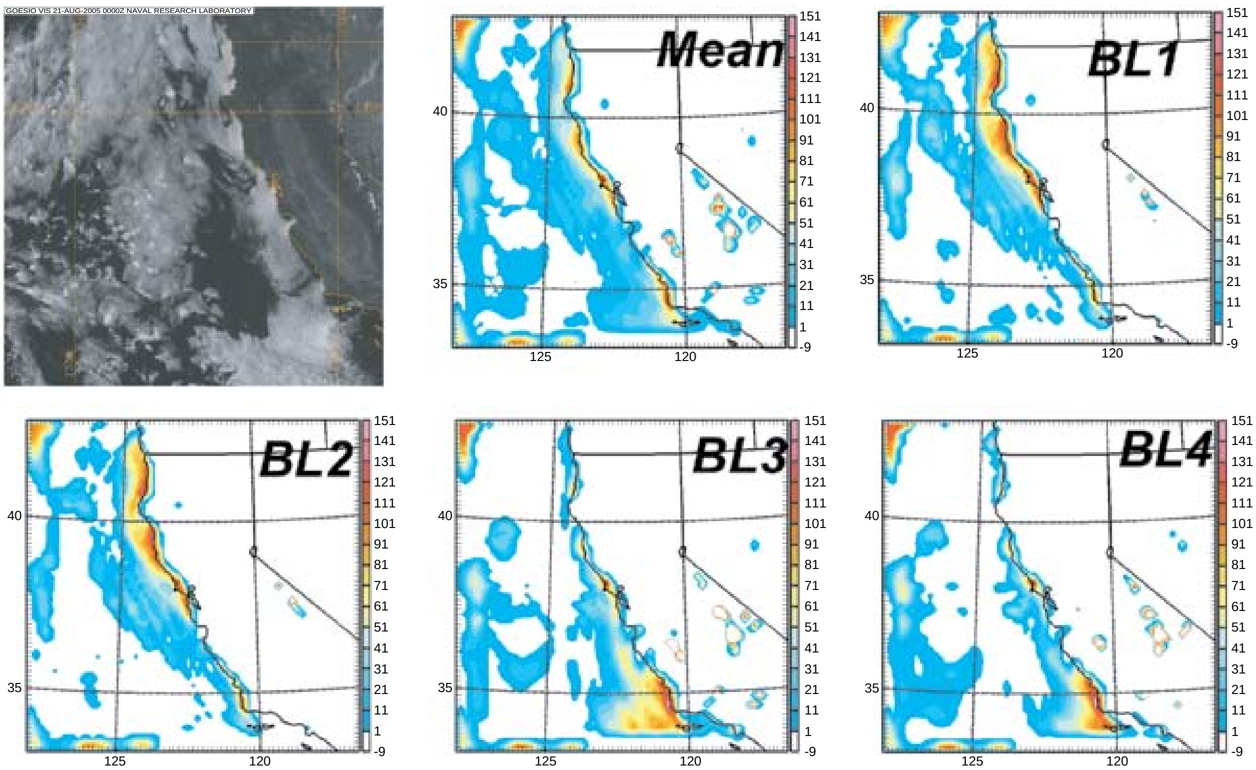


**FIGURE 8**
Example of the sensitivity of model-predicted clouds (vertically integrated clouds shown in color) to various formulations of the boundary layer parameterization (BL1 through BL4). Mean = ensemble mean.